CALFED BAY-DELTA PROGRAM

NEWS FROM THE CALFED SCIENCE PROGRAM

ScienceAction

BIG PICTURE

Tracking Organic Matter in Delta Drinking Water

Decaying plants, atomic bombs, ozone and computers all play a role in the state's efforts to improve the quality of the water filling the faucets of 25 million Californians. Scientists measuring sound, light and traces of radioactivity; plant managers disinfecting drinking water with ozone and chlorine; and regulators trying to protect human and ecosystem health have all been struggling to better understand and manage one particular ingredient in the Sacramento-San Joaquin Delta water supply: organic material. In the last few years, they've been making headway.

Delta water contains a lot of organic material — material naturally produced by our ecosystem as all living things live, grow, die and decay. It is when these waters are exported and treated to make them potable that the organic material can become troublesome. During treatment, the organic material may react with disinfectants to form chemical byproducts harmful to humans (see *Health Concerns* p.2). To protect human health, the U.S. Environmental Protection Agency (EPA) regulates disinfection byproducts in drinking water. In recent years, water managers have found it increasingly difficult to meet EPA standards, and have been looking for ways to manage organic material at the source rather than at the treatment plant.

The organic material in Delta water enters drinking water diversion facilities from many sources – the drains drying island farm fields, the runoff from our cities and croplands, the rivers flowing from foothills to water intakes, the wastewater from our sewage treatment plants, the wetlands in and upstream of the Delta, and the floodplains and shallows downstream. All these sources support aquatic plant growth and the food web throughout the Estuary.

For decades, scientists at the U.S. Geological Survey (USGS) and the California Department of Water Resources (DWR), among others, have been studying these sources and the fate of organic material as it moves through the Delta. This publication is not a comprehensive review of all their work (see *Resources* p.8). Rather it focuses on some of the recent findings of Brian Bergamaschi, Roger Fujii and Tamara Kraus of USGS and James Sickman of U.C. Riverside, formerly with DWR. It also, in the tradition of all six *Science Actions* published by the CALFED Science Program since 2001, seeks to share these findings in a style accessible to scientists and non-scientists alike.

Using sophisticated analytical methods, Bergamaschi, Fujii and other scientists on their research team have begun to tease apart the sources and properties of the organic material in water exported from the Delta for human use. Their focus has been on the organic material dissolved in water, called dissolved organic carbon, or DOC (see below). Their results indicate that there is no silver bullet for drinking water managers that can be aimed at one bad source of DOC. Indeed scientists are increasingly sure that the culprit is not just the Delta, or the organic soils of its peat islands, or wetlands, but diverse sources to be found throughout the watershed (early findings to this effect are covered in the August 2004 *Science Action: Demystifying the Delta*).

USGS's Brian Bergamaschi and Gail Wheeler lowering hydro-optic instruments into a tidal slough on Browns Island.

"When we began our research, we all thought that relatively pristine river water came flowing through the Delta, where pump-off from islands added virtually all of the DOC," says USGS's Bergamaschi. "However, when we looked at the chemical specifics of the stuff in the water used by Contra Costa Water District or exported to the State Water Project by the pumps at Banks, the types of carbon that were there couldn't be explained as a simple mixture of river and island carbon. Virtually everything about the chemical signature tells us there are other sources." On an annual average, he's found that about 25 percent of exported DOC is produced within the Delta, and the remainder is contributed by rivers and upstream sources (see diagram p.6).

Each source produces DOC with a different chemical composition. The composition affects both the potential for formation of disinfection byproducts (some DOC types are more reactive than others), and the potential that some of the DOC will be taken up by microbes — DOC is an essential nutritive material that provides three-quarters of the energy that fuels the aquatic microbial food web in the Estuary (see *Resources* p.8 and *Food Web* p. 6).

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DOC DEFINED

Carbon is one of the building blocks of all life. Watersheds, wetlands, cities, suburbs and farm fields all naturally produce and transport organic carbon, and as a result it is ubiquitous in water – every liter of Delta water contains thousands of different organic compounds. As water travels downstream, water quality shifts from carbon-poor headwaters to carbon-rich rivers meandering through floodplains and wetlands. In scientific terms, organic carbon is often classified as total, particulate or dissolved (TOC, POC or DOC).

Most of the research reported here concerns DOC. DOC is the dissolved residue of living things, and together with POC, makes up TOC. DOC is defined as the material that passes through a filter with holes about half the size of a typical bacterium. POC is all the material filtered out. Scientists can identify different origins of DOC by examining the age, chemical composition and spectroscopic properties (color) of samples. In general, DOC is beneficial to aquatic organisms and largely benign for humans.

Tracking Carbon

The chemical composition of DOC derives from its source, as well as from the processing that occurs in the environments through which it travels. For example, DOC from algae is more readily used as food by aquatic organisms and forms fewer disinfection byproducts than DOC derived from wetlands or soils. Scientists say that both the source and the degree of environmental processing, in combination, determine the amount and composition of DOC present in river and Delta waters.

"We can now cut the pie up into different sources, and things are more complicated than we thought," says Bergamaschi. "In fact, currently in the Delta we see times when most of the DOC exported is derived from wetlands, and other times when the majority comes from islands, and still other times when it does not appear that these and other in-Delta sources are contributing much carbon at all, and it is mostly riverborne DOC that is getting passed through to the export pumps."

These and other findings explored in the following pages derive from USGS studies funded, in part, by the state and federal CALFED Bay-Delta Program. The CALFED Program's goal is to balance competing needs for the state's freshwater supplies for urban, industrial and agricultural uses while protecting endangered fish and wildlife and restoring the creeks, rivers and watersheds flowing into the Sacramento-San Joaquin River Delta and San Francisco Bay. In light of the high cost and technical difficulty of treating Delta water, the 2000 CALFED Record of Decision (ROD) set an average target concentration at drinking water intakes of 50 micrograms per liter (ug/L) bromide and 3 milligrams per liter (mg/L) total organic carbon (TOC). If such targets cannot be achieved through management of source waters, CALFED allows for solutions that include blending with more pristine water and/or the use of treatment technologies.

The research conducted by the USGS team, as well as extensive studies by other agencies, now combine to help water managers achieve the targets in the ROD by clarifying sources and types of DOC, and by exploring how seasonal and hydrologic changes affect DOC.

"What's different about this DOC issue is that it involves direct impacts on humans," says CALFED lead scientist Mike Healey. "Somehow we need to maximize the food web benefits of organic carbon for fish and wildlife but minimize the human health risks posed by disinfection byproducts."

TAKE-HOME POINTS

- DOC comes from a multitude of sources within and upstream of the Delta, the mix of which varies with land use, climate, season and hydrology, among many factors. DOC does not come from a few easily mitigated sources.
- On an annual average, only 25 percent of DOC exported through the State Water Project is produced within the Delta.
- Among in-Delta DOC sources, island drains and wetlands are the most important. Urban runoff is a growing concern.
- The source and composition of DOC can affect the amount of disinfection byproducts that form as much as the DOC abundance in the system can.
- Real-time, high-frequency analysis of DOC is necessary to capture the effect of fluctuating aquatic conditions caused by tides, wind and seasonal changes on DOC quality, quantity and sources.
- There is no simple way to dramatically reduce DOC in export water. Managing the timing of exports can help minimize DOC but environmental concerns limit this approach.
- Since watersheds — and nearly everything that populates the landscape within them — naturally produce DOC, reducing sources of THM precursors to target levels may not be possible. Land use changes should be undertaken with careful attention to the impacts on DOC export.
- Improving treatment to keep concentrations of harmful disinfection byproducts at low levels, despite changing climate and land use conditions in California, will be costly.

HEALTH CONCERNS

All drinking water goes through some kind of disinfection process. Disinfection can kill pathogenic microorganisms, resolve taste and odor issues, and treat some problematic organics. Disinfection can be achieved with the help of chlorine, chloramines, ozone and physical disinfection tools, such as ultraviolet radiation (UV) and membranes that inactivate or remove microorganisms.

Several types and classes of potentially harmful disinfection byproducts (DBPs) may form as a result of the presence of DOC, depending on the water treatment process used. The most commonly used disinfection process is chlorination, which results in the formation of trihalomethanes (THMs) and haloacetic acids (HAAs), the two most prevalent classes of disinfection byproducts.

THMs and HAAs are not the only disinfection byproducts that are of concern for drinking water treatment. More than 600 disinfection byproducts have been reported in the literature for the major disinfectants. Both THMs and HAAs are currently regulated by EPA; managers assume (with reasonable confidence) that treating for THMs and HAAs will also address similar but lesser-known byproducts.

Though ozone is often thought to be the disinfectant of choice for source water containing DOC, disinfection byproducts can still form during ozonation. More byproducts may be produced, for example, if the water undergoing ozonation also contains bromide — a salt derived largely from seawater intrusion into the Delta. The bromide may react in two ways. First, when ozone is used for treatment, bromide forms bromate, a regulated carcinogen. Second, when chlorine or other disinfectants are used, bromide reacts with the disinfectant to form bromine, which in turn reacts with the DOC to form disinfection byproducts that are more harmful than their chlorinated counterparts (for more information on bromide, see *Resources* p.8).

It is important to note that only a few percent or less of the DOC present in water actually forms disinfection byproducts during treatment. The quality — the nature and properties — of the DOC may be just as, or more, important than the concentration in terms of forming disinfection byproducts (see p.5).

Ozone generator at the Contra Costa Water District's Bollman Water Treatment Plant near Concord. Source: CCWD

RESEARCH

DOC Dynamics

Instruments that bounce light and sound off tiny particles in the water have played a key role in research tracking the movement of organic matter into and out of Delta channels and islands. In a two-year study of Browns Island conducted by USGS, for example, these instruments — which include a flourometer (which measures fluorescence, or "glow") and a spectrophotometer (which measures light absorption) — did their job every 15 minutes for months at a time. Such a high frequency of measurements is critical in an estuarine system where tides, currents, salinity, DOC and flows can all change minute by minute.

"This is a high-tech way of looking at the color of a mud puddle," says Brian Bergamaschi. "The wavelength at which the sample water absorbs light and fluoresces is physically related to the components of DOC."

USGS scientists preparing to deploy an optical instrument package in a tributary of the Sacramento River. Once deployed in several meters of water, such instruments are programmed to come to life every 15 minutes — firing off a burst of sound to measure currents and turbidity, shining a bright light to catch refractions off particles floating around, and sucking water through various sensors to measure glow and light absorption. Pictured here: Bryan Downing, Brian Pellerin and Brian Bergamaschi.

Over the years, Bergamaschi's team has deployed these very specialized sensors at a dozen or more locations around the Delta and upper watershed. Such instruments have helped scientists document and trace the DOC arriving at the export pumps back to its origins. Combined with lab tests on the DOC's chemical composition and age, their results can tell the team where the DOC came from and traveled to, and what may have happened to it along the way.

SOURCES OF DOC

The sources of DOC to Delta waters include rivers, island drains, wastewater, wetlands, agricultural and urban runoff, and algae growth, among others. The DOC may enter the Delta via groundwater and subsurface drainage, as well as via the surface water system.

In terms of upstream sources, rivers — which drain agricultural, urban and natural watersheds into and through the Delta — are the largest source of DOC. In terms of in-Delta sources, island drains have long been thought a major contributor to DOC arriving at the drinking water export pumps. Most islands are highly subsided (up to 25 feet below sea level) because of oxidation of their peat soils. To offset the influx of water that seeps through the levees and accumulates from irrigation and precipitation, water must be continually pumped off the islands into neighboring Delta channels. Groundwater flow through oxidized peat soil layers may also contribute DOC.

USGS research results indicate that DOC concentrations in peat soil waters may exceed 100 mg/L. However, peat soils are not necessary to produce elevated DOC concentrations in soil water. Water from the soil in a San Joaquin Valley field had DOC concentrations that ranged up to 70 mg/L although the soil itself contained less than 1.5 percent organic carbon. In general, although the concentrations of DOC found in peat island drains are high, and the area used for agriculture in the Delta is large, research results indicate other sources of DOC within the Delta may be of equal or greater magnitude than the island drains.

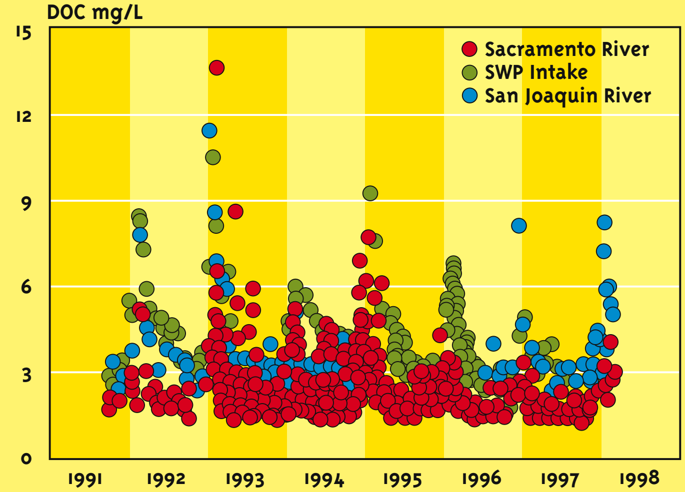
Wetlands, both within the Delta and as part of upstream floodplains and riparian zones, are another source of DOC. Wetland DOC concentrations may exceed 80 mg/L in surface water in the soils. However, wetlands are not automatically large sources of DOC; a particular wetland may release insignificant amounts of DOC, depending on its configuration. Older, larger and more developed wetlands tend to trap rather than export DOC because water flowing through them follows more complex channel configurations and encounters more diverse and dense vegetation. Most of the wetland relics still remaining in the Delta, however, are small and well connected to the river by tidal channels, attributes that yield larger amounts of DOC to the surrounding channel waters.

Runoff from agricultural fields, natural landscapes and urban environments may lead to elevated DOC concentrations in surface waters, as well. Runoff and wastewater entering the Delta are also replete with nutrients that can stimulate algal production — another source of DOC. However, there is little evidence to suggest that algal production is a major contributor to elevated DOC concentrations in the Delta.

More details on urban contributions to DOC in the Delta have recently emerged from research by Jim Sickman of U.C. Riverside and Mike Zanoli of DWR (see charts p.5). Their research indicates that urban sources contributed 17 percent of the annual load of organic carbon (TOC) in the river below Sacramento (load is a measure combining concentration and flow).

Continued page 4

DOC IN RIVERS & INTAKES, 1991-1998



Time series showing similar timing and magnitude of peaks at SWP intake and major Central Valley rivers.
Source: Data from DWR

DOC Dynamics

In sum, analysis of long-term records of the composition of DOC at the SWP Banks Pumping Plant confirms the existence of multiple sources. The composition cannot be fully explained as a simple mixture of river and island drain DOC. Further analysis suggests the composition is best explained as a mixture of material derived from rivers, wetlands, and islands. Other sources likely exist also, but have not yet been identified.

SEASONAL CHANGES

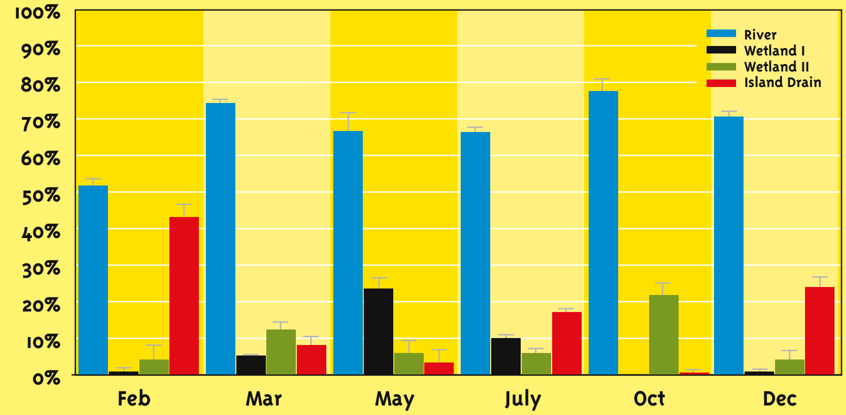
Scientists have found that the concentration of DOC throughout the Sacramento and San Joaquin valleys and in the Delta peaks with river flows in the late winter and declines through the summer. This is similar to the trend observed in major DOC sources, such as tidal wetlands, peat island drains and agricultural drains.

They've also demonstrated that the DOC added from sources within the Delta varies with season, and is highest in the winter — when it accounts for 50 percent of the DOC arriving at the Banks export pumps. This is the time of year when DOC loads from rivers are at their highest as well. During late summer and fall, periods of low river flow, there is little contribution from in-Delta sources, and river DOC accounts for up to 90 percent of the DOC arriving at the Banks pumps.

In terms of specific sources and their contributions in different seasons, scientists found larger contributions from wetlands between early spring and fall, and larger contributions from island drains in early winter. For example, concentrations measured in peat island agricultural drainage waters varied seasonally from 10 to 70 mg/L. Similar seasonal variability was also common outside the Delta; concentrations in relatively pristine areas of Willow Slough ranged to over 10 mg/L in the winter. Steelhead Creek, which drains an urban area in Sacramento, had spikes of DOC between 25 and 50 mg/L during first flush storms.

The relationship between DOC concentration and precipitation is not simple. "We all have this classic thing welded into the collective unconscious that everything in the Delta is precipitation driven. But our analysis of the data shows that this is simply not the case in terms of DOC," says Bergamaschi.

SEASONAL DOC CONTRIBUTION FROM WETLANDS, ISLANDS & RIVERS



Samples taken from rivers, island drains and large, well-developed wetlands in the Delta. Source: Kraus, Bergamaschi, et.al., USGS

Somewhat surprisingly, USGS scientists found no significant difference, beyond annual seasonal variations, in DOC concentration between wet and dry years in the Delta (see chart p.3). DOC concentration does exhibit a relationship with temperature, however, peaking in late winter as the landscape starts to warm up. Scientists have not really figured out why temperature appears to be more closely related to the timing of DOC concentrations than precipitation.

PROCESSES & TRANSPORT

DOC concentrations in the Delta are the broad expression of a combination of physical, geological and biological processes, rather than the contribution of a single or small number of sources. As organic carbon moves through soil and water, it degrades in the sun, interacts with microbes, reacts with chemicals in the soil and water, and mixes with other kinds of organic matter in transport. Each instance of degradation or transformation alters its chemical characteristics.

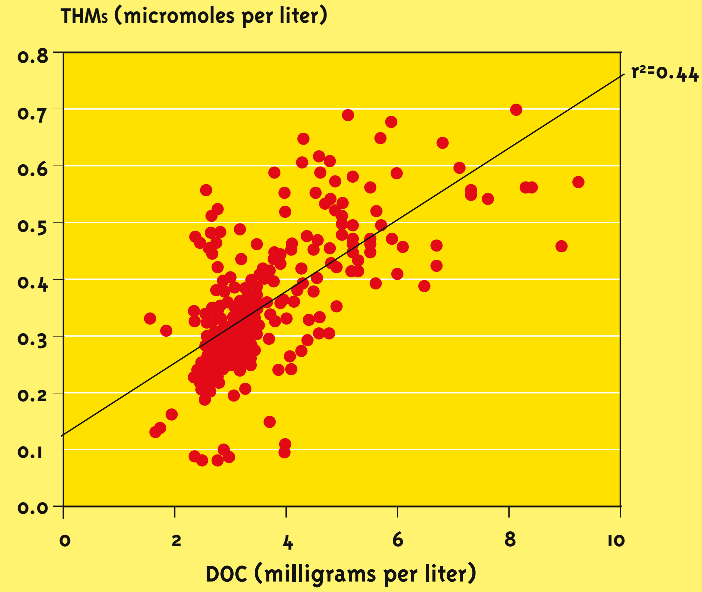
"We can use the proportions of certain chemicals and markers as a 'fingerprint' to establish what the contributors were to any given water sample," says Bergamaschi, adding that most of the important chemical changes happen within the first few days of degradation, with progressively less happening over the course of the weeks it may take for DOC from a distant source to travel downstream. "All of these reactions are rapid in the beginning, but slower over time, so the fingerprint of the source material remains distinctive even at the pumps," he says.

DOC concentrations change as the material moves from watersheds into rivers and through the Delta. USGS studies indicate that the concentration of DOC increases on average by 30 percent as river water transits the Delta, but the increase is seasonally variable. DOC also changes as river water sits in reservoirs or water aqueducts awaiting treatment.

QUANTITY & QUALITY

Anyone who has ever put a stained cotton shirt in the laundry with a dash of chlorine bleach knows that different kinds of organic compounds react

DOC & THMs AT BANKS PUMPING PLANT



The variability in the quantity of DOC only explains 44% of the variability in THM formation — underscoring the differences in the quality of organic carbon. Source: Data from DWR

differently. Just like in the drinking water treatment plant, the organic compounds in your coffee or wine stain react with the chlorine, but the organic compounds in your shirt — the cotton fibers — don't react. The same is true for the many compounds that make up DOC — some react quite easily, many react quite slowly and some don't react at all.

USGS studies found that DOC concentration explains less than half of the variability in THM formation (see chart p.4). The amount of THMs formed in samples containing the same concentration of DOC and collected from across the Delta varies by a factor of five, similar to the variability caused by changes in DOC concentration at Banks. In particular, USGS studies show that wetland DOC formed more THMs than most other sources, while island drains had higher HAA formation.

The reason different types of DOC react to a greater or lesser extent is because some sources build more of the kinds of molecules that react with chlorine to form disinfection byproducts than others. Among plant sources, for example, corn contains few of what scientists call "structural biopolymers" — which is why you can so easily knock a cornstalk down. Without these particular polymers, the DOC from a cornfield would break down, be much more quickly consumed in the ecosystem and be less reactive during drinking water treatment than the DOC from, for example, more woody and structurally strong plant materials, such as vines and trees.

OLD & NEW CARBON

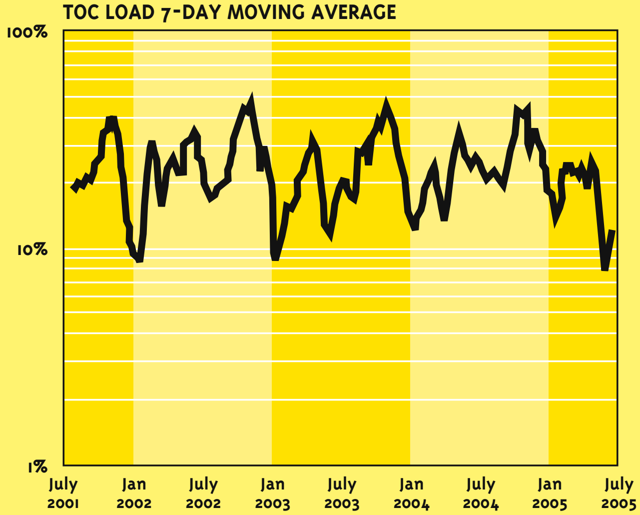
Organic carbon comes in many different types, from the fresh material created by annual crop residues or newly growing algae to ancient material derived from soils and fossil fuels thousands to millions of years old. The age of the organic carbon provides evidence of its origins — peat-derived DOC is old, and algal DOC nearly modern, for example. Jim Sickman and DWR's Carol DiGiorgio have been using radiocarbon dating to measure the age of organic carbon in various places in the Delta and its watershed. As plants grow, they take CO_2 out of the atmosphere, and a small fraction of that carbon is radioactive ^{14}C (carbon 14) — tracing back to Cold War testing of atomic weapons and to natural formation in the atmosphere. When plants die, become part of the soil and cease exchange with the atmosphere, radioactive decay begins. "It's like a clock starts when the animal or plant dies," says Sickman. He's used radiocarbon dating to provide evidence, for example, that the age of the DOC arriving at Banks was not as old as the carbon in the island drains, confirming that there must be a more modern source.

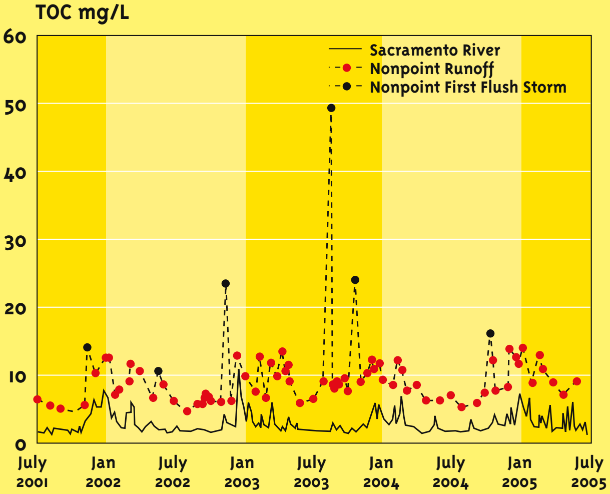
In his research, Sickman also found evidence of very old carbon in the San Joaquin River. The way he explains it, most of the DOC in rivers comes from "humic" substances produced by the microbial degradation of soil and plant materials, which range in age from a few decades to hundreds of years old. In the San Joaquin River, however, he also found non-humic substances in DOC that were many thousands of years old. "This is too old to come from soil organic matter," he says, suggesting these components can more likely be traced to the petroleum-based carriers

POINT & NONPOINT TOC CONTRIBUTIONS FROM URBAN SACRAMENTO AREA

These two charts quantify total organic carbon loading from point and nonpoint urban sources within the metropolitan area of Sacramento and compare these loads with the amount of organic carbon carried in the downstream Sacramento River. The top chart shows how much of the total organic carbon (TOC) in the river below the city is contributed from urban sources. The second chart illustrates how high TOC concentrations in nonpoint urban runoff are relative to background levels in the river.

PERCENT URBAN CONTRIBUTION TO SACRAMENTO RIVER TOC LOAD 7-DAY MOVING AVERAGE

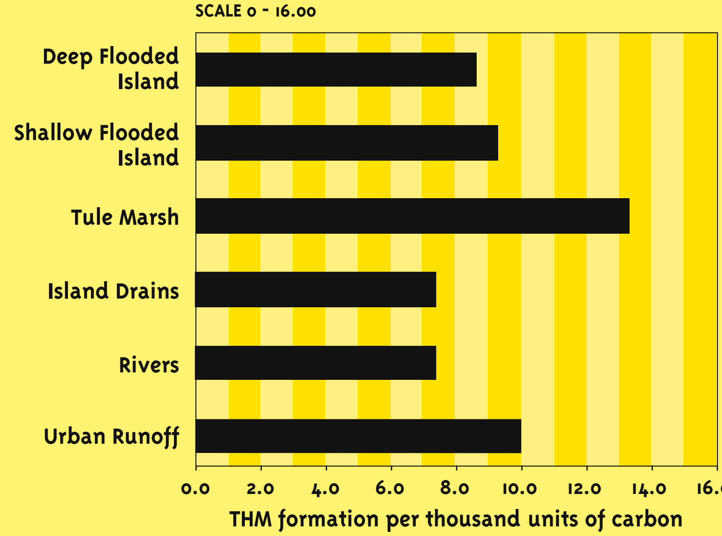




Source: Sickman, U.C. Riverside, and Zanoli, DWR

THM PRECURSORS IN DIFFERENT SOURCES

SCALE 0 - 16.00



Source: Kraus, et al., USGS

of agrochemicals, which contain fossil fuel materials formed eons ago deep in the earth.

In other radiocarbon dating research, nonpoint DOC in runoff from the Sacramento area was found to be substantially older than DOC just downstream in the Sacramento River. In the coming year, scientists will attempt to reverse the radiocarbon sleuthing process in an effort to tease out the most reactive DOC forming disinfection byproducts. In this research, they plan to react Delta DOC with chlorine, and then capture any chloroform produced (one of the major THMs). Once the chloroform is purified, it will be radiocarbon dated.

A NEW CONCEPTUAL MODEL

Results from these recent studies have allowed scientists to update USGS conceptual models of DOC in the Delta (see diagram below). In this updated model, rivers supply the majority (50-90 percent) of DOC found in Delta waters. Seasonal differences in river contributions of DOC are determined by a combination of runoff timing and basin-wide biogeochemical processes. On an annual basis, island drains and wetlands each appear to contribute similar proportions of DOC within the Delta, with island drains contributing a greater proportion in early winter, and wetlands a greater proportion from early spring into the summer. In the late summer and fall, a period of high State Water Project export, in-Delta sources appear to contribute little to the export load of DOC.

Together these findings emphasize the need to monitor DOC components and how they respond to ecosystem restoration, flow alteration and land use changes in the Delta. Land use changes of concern include not only current urbanization but also the future of agriculture in the Delta. According to Sickman, "The fact that we're seeing carbon in the island drains that's 1,500-4,000 years old suggests to me that we're not being good stewards of the organic matter in the soil. We're losing it. In a way, we've already written the obituary on farming in the central Delta a few decades from now."

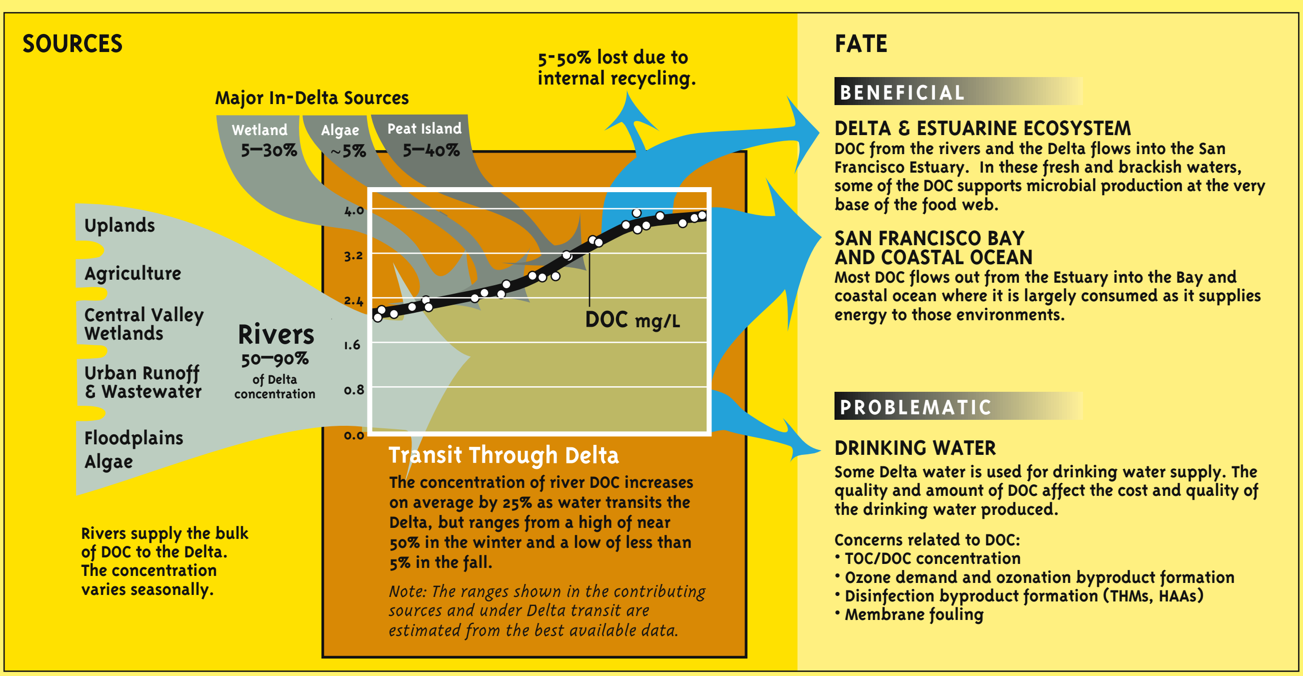
THE FOOD WEB

Organic carbon helps fuel the aquatic food web in different ways, depending on its form. Some forms are edible, and some are not; some are the right size to be eaten, and some not. When scientists and resource managers call for increased production of carbon in the ecosystem, to help feed the fish, the carbon they especially want is from algal production (particulate organic matter, or POC) not from DOC. Research has shown that the food web energy supply to fish is largely through the algal pathway (POC), and only a small fraction through the detrital, or DOC, pathway (see *Resources*, p. 8).

Algae directly support the production of plankton and feed fish. DOC, however, gets used in much lower trophic layers of the food web – at the level of microbial production. So although DOC may represent a mass of carbon larger than the mass produced in plankton (POC) in the Delta, DOC only contributes a small fraction of the energy consumed by fish. The fraction is small due to the low efficiency of energy transfer at each step up the food web, and to the larger number of steps between the microbial food web, the planktonic food web and the fish. To sum up, in terms of total ecosystem energy budget, most of the energy is consumed by the lower food web before it gets to the upper levels (if it ever does) and the low part of the food web is largely supported by DOC.

Promoting fish food — algal production in the Delta — by restoring wetlands and floodplains, or promoting exchange between land and water, will not necessarily increase problematic DOC. When algae decompose and release DOC, the resulting DOC degrades quickly and more fully than DOC from other sources. This is why, under current conditions in the Delta, algal production appears to add little to the exported DOC pool. As such, returning algal production in the Delta to historic levels will likely not be a problem for drinking water.

SOURCES AND FATE OF DOC IN DELTA WATER - CONCEPTUAL MODEL



Source: USGS

MANAGEMENT

Perspectives on Our Options

New findings about how, when, where and what kind of dissolved organic carbon occurs in the Delta have the potential to reshape thinking on everything from the way the Delta itself is configured to the way water is treated at the tail end of the export canals. To explore how science might translate into action, CALFED writers asked scientists and various water resource managers to speculate about the implications of recent research.

By far the most intriguing finding, say experts, is that there are many, not just one or two, sources of DOC and not all of them are in the Delta itself. According to the State Water Resources Control Board's Tom Howard, these findings reduce the potential water quality benefits of the proposed peripheral canal.

"In the past, bypassing the Delta because of water quality concerns was considered by many proponents to be an adequate rationale for the peripheral canal," says Howard. If river water itself carries significant concentrations of DOC, however, the water quality benefits of a canal become more limited. As Greg Gartrell of the Contra Costa Water District puts it,"This suggests that it doesn't matter where you put the intakes, you are still going to be subject to significant inputs of DOC."

However, warns Howard, "I'm not sure to what extent this will create a radical change in perspective." Even if a peripheral canal will not make DOC inputs go away, it would still have significant water quality benefits in terms of reducing bromide levels, which are a large part of the problem in treating Delta water, experts say.

In the meantime, managers point out that upstream Sacramento River DOC concentrations still seem to be less than in the water arriving at the Banks pumps, and that with a peripheral canal, river inputs can be better managed. Organic carbon loading on the rivers, especially the Sacramento, often varies rapidly and therefore, the bypass flow could be shut off for a short period of time (hours to days) while the poor-quality water flows by and opened back up when the better quality water returns, say managers.

WETLAND RESTORATION

One finding of the new research is that the Delta's few remaining wetlands appear to be major contributors of DOC during some times of year, including a type linked to the elevated production of THMs.

Carol DiGiorgio of DWR's Municipal Water Quality Investigations branch collecting a drainage water sample as part of a special study at Staten Island in the northern Delta.

"Picking locations for wetland restoration projects will become very important if there are very high inputs of THM precursors in some areas," says Howard. He is skeptical that the findings on wetlands and DOC will have a large impact in the long run. "These are all things that have to be weighed in the decision-making process, but whether they would tilt the scale in any particular direction, I'm not sure," he says, noting that a similar issue arose because of mercury releases associated with wetland restoration work.

"We will need to allocate land use in a way that maximizes the beneficial effects on the ecosystem and also protects drinking water," argues the Metropolitan Water District's Rich Losee. "If we go willy-nilly into restoration without protecting the sources of drinking water, we might end up doing more harm than good."

Brian Bergamaschi of USGS has scribbled on the back of an envelope in an effort to guesstimate just how much harm we might be talking about. His calculations suggest that adding 30,000 new acres of wetlands in the Delta might, at the worst time of year – early spring, raise the concentration of DOC at Banks about half a milligram, but that the average increase in wetland input over the whole year would be much less than half a milligram because so much water is exported in other seasons when wetland contributions are much lower.

"This calculation indicates that restoration could be a bit of a problem, but it is also shows that restoration is not likely to make the problem twice or three times worse than it is now, unless we do everything very wrong," says Bergamaschi. "Certainly, even a small increase in DOC has the potential to be very costly if it puts you over a regulatory limit or restricts your ability to blend water to comply. But I suspect we can build wetlands that provide greater algal primary production while not appreciably degrading drinking water quality or increasing treatment costs in any kind of nightmare scenario. We just have to do it very carefully and pay attention to the particulars of each site."

Scientists are more concerned about the impacts of urbanization than restoration. "The DOC is coming off what we're doing right now in terms of land use, not off what happened long ago," says Bergamaschi. Urbanization seems to have the same effect on soil organic matter as agriculture does, adds U.C. Riverside's Jim Sickman.

TIMING OF PUMPING

Water managers may be able to reduce the amount of DOC and associated disinfection byproduct formation potential in drinking water by being selective about when they take water out of the Delta.

"Something like half of the water that goes into the water projects goes into it for irrigation purposes, where DOC is not a bad thing," says Bergamaschi. "It's just when they're filling drinking water reservoirs, when they're straight pumping to Southern California or when they're parking it somewhere for future drinking water use, that DOC is important."

"There are things you can do with respect to timing," says Gartrell. "We already limit what we take into the reservoirs with regard to salt, and that tends to coincide with low DOC for our operations."

The timing equation became more convoluted in December, when U.S. District Judge Oliver Wanger issued a complicated ruling designed to protect Delta smelt. The ruling, which could decrease pumping by 30 percent, set water flow targets from late December through June, the primary spawning season when smelt are in particular danger of being sucked into the pumps.

"We are looking at the water quality implications of the Wanger decision," says Losee. "It probably means a shift from winter pumping to summer. But by shifting to summer, we will increase bromide exposure, which could be a huge problem," since bromide can also contribute to the formation of carcinogenic disinfection byproducts. Losee says that he and his colleagues are trying to persuade water management modelers to at least crudely incorporate organic carbon gain and loss dynamics from the dominant sources — rivers, wetlands, urban and agriculture — in their models.

TREATMENT

Opinions differ over whether the best — and most realistic — approach might just be to forget keeping DOC out of drinking water and focus on improving treatment to reduce dangerous disinfection byproducts.

"Fundamentally I haven't seen that water quality drives management issues," says Howard. "The value of the water exceeds concerns over water quality and the cost of treating it," adding that water managers might use the findings on DOC to treat water differently at different times of the year.

"Some utilities are changing their approach to treatment," agrees Losee. "Many are switching from chlorine treatment to ozone, but that has its own set of problems. Ultraviolet light is being looked at, but is not adequate to treat pathogens under all Delta conditions." Gartrell adds that "there will be more and more agencies going to membrane filtration that can take out molecules and pathogens."

Losee still thinks prevention is the best medicine. "It is not a solution to say contaminants, both natural and manmade, can be taken care of at the tail end of the pipe. If we change the way we allocate the resource, we could dramatically reduce the need for additional treatment." More efforts could be made to keep poor-quality San Joaquin water out of the drinking water blend, or not to waste less DOC-laden water on farm field irrigation. Other preventive approaches might include more efforts to conserve soil and organic matter in the Sacramento and San Joaquin valleys, or to treat storm runoff in ponding basins, where natural processes could consume both excess nutrients and DOC.

In the end, the recent research conclusions about the multiplicity of DOC sources, the variation in the quality of DOC and the seasonal ups and downs in DOC raise questions about water quality standards, targets based on long-term averages, source control and treatment options (see *Take-Home Points* p.2). Some of these questions may be addressed as CALFED works to finalize a drinking water assessment released in draft form in October 2007 (see *Resources* opposite); such an assessment might also benefit from some solid economic analysis of the costs of keeping DOC out of the system versus the cost of more treatment, experts say. Other questions, especially about how we monitor and trace THM precursors in DOC, will be left to the next round of science.

Aside from local concerns about drinking water, this research also contributes to the big picture on the planet. As Sickman sees it, "Recent concerns over global warming show that management of carbon, both in the atmosphere and in our water, is critical if we are to sustain the water supply needed by both our environment and human society."

CONTACTS & RESOURCES

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